Continuation of Field Research on Advanced Coatings for Mussel Control

Research and Development Office
Science and Technology Program
(Final Report) ST-2018-7089-01
Mission Statements

Protecting America's Great Outdoors and Powering Our Future

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Disclaimer:
This document has been reviewed under the Research and Development Office Discretionary peer review process https://www.usbr.gov/research/peer_review.pdf consistent with Reclamation's Peer Review Policy CMP P14. It does not represent and should not be construed to represent Reclamation's determination, concurrence, or policy.

Information in this report may not be used for advertising or promotional purposes. The enclosed data and findings should not be construed as an endorsement of any product or firm by the Bureau of Reclamation (Reclamation), U.S. Department of the Interior, or the Federal Government. The products evaluated in this report were evaluated in environmental conditions and for purposes specific to Reclamation’s mission. Most of these products were originally developed for the marine environment and not necessarily for use in freshwater. The data should be viewed as site specific and not necessarily applicable to all freshwater exposure conditions. Reclamation gives no warranties or guarantees, expressed or implied, for the products evaluated in this report, including merchantability or fitness for a particular purpose.
Continuation of Field Evaluations on Advanced Coatings for Mussel Control

### Abstract
This report is a continuation of field testing of coatings for mussel control. The goals of the past three years were to:

1. Continue evaluating commercially available foul release materials that have been proven to work in previous research.
2. Continue evaluating new products or experimental products that may represent advancements in technology through the use of Material Transfer Agreements (MTA).
3. Continue evaluating the scaled-up coated trashrack panel.

### Subject Terms
- Invasive Mussel Control
- Quagga Mussels
- Zebra Mussels
- Foul Release Coatings
- Fouling Prevention
Continuation of Field Evaluations on Advanced Coatings for Mussel Control

Prepared by: Allen Skaja, Ph.D.
Protective Coatings Specialist, Materials and Corrosion Laboratory, 86-68540

Checked by: Stephanie Prochaska, M.S.
Materials Engineer, Materials and Corrosion Laboratory, 86-68540

Technical Approval: Richard Pepin, PCS,
Protective Coatings Specialist, Materials and Corrosion Laboratory, 86-68540

Peer Review: William Kepler, Ph.D., P.E.
Supervisor, Materials and Corrosion Laboratory, 86-68540

For Reclamation disseminated reports, a disclaimer is required for final reports and other research products, this language can be found in the peer review policy:

This document has been reviewed under the Research and Development Office Discretionary peer review process https://www.usbr.gov/research/peer_review.pdf consistent with Reclamation's Peer Review Policy CMP P14. It does not represent and should not be construed to represent Reclamation’s determination, concurrence, or policy.
Acknowledgements

We’d like to thank the Bureau of Reclamation (Reclamation) Research and Development (R&D) Office - Science and Technology (S&T) Program for funding this research. We’d also like to thank the Bureau of Reclamation Lower Colorado (LC) Region, the LC Dams Office, and the staff at Parker Dam for all of their in-kind contributions, access, and support.

Acronyms and Abbreviations

Bureau of Reclamation, Reclamation
Foul Release Coatings, FRC
Lower Colorado, LC
Material Transfer Agreements, MTA’s
Materials and Corrosion Laboratory, MCL
Pacific Northwest National Laboratory, PNNL
Pittsburgh Paint and Glass, PPG
Research and Development, R&D
Science and Technology, S&T
Executive Summary

Invasive mussels are a nuisance mollusk that attach to submerged surfaces. They also attach to hydraulic structures and can impair their function.

One approach to prevent or reduce the effects of mussel buildup (fouling) is to use antifouling or foul release coatings (FRC). Antifouling coatings contain a biocide that is designed to deter fouling. Foul release coatings rely on physical properties of the coating to impair adhesion of the mussel to the coating surface.

This report summarizes test results from testing performed from 2015 to the present. These results are part of the ten year research and testing program started in 2008 performed by the Materials and Corrosion Laboratory (MCL) researchers on antifouling and foul release coatings to deter mussel fouling. Parker Dam, at Lake Havasu Reservoir on the border between Arizona and California is the field test site to evaluate materials and coatings in low-flowing and flowing exposure conditions. Several types of test panels, including a large mock-up of a trashrack panel are submerged at this location to test newly formulated and existing commercial coatings for resistance to mussel fouling and durability. The trashrack was coated with four commercial FRC, Intersleek 970, Sigmaglide 890, Sher-Release, and Seaspeed V5 to better model an actual submerged structure common in many reservoirs to determine if the softer silicone coatings were durable enough to last long term.

Refer to the Background section of this report for a summary of prior testing and a table of all previous reports related to this program. Ten peer reviewed reports have been prepared to date to document test results.

The present work is a summary of the past three year’s research, which was to:

1. Continue evaluating commercially available foul release coatings proven to work in previous research.
2. Continue evaluating experimental formulated products that may represent advancements in technology through the use of Material Transfer Agreements (MTA).
3. Continue evaluating the full sized coated trashrack panel.

Ten commercial coating systems and one metal alloy are still performing well. The commercial coating systems primarily rely on silicone foul release technology. The metal alloy is based on copper. Four commercial coating systems were removed from the test program because of poor performance.

Inspections showed that for the commercial FRC, fouling began with algae. The algae subsequently allowed for the attachment of mussels. In other words, the fouling builds up and the coatings are no longer self-cleaning under the test conditions (flowing water). However, the algae and mussels were easily removed.

In addition, we expanded existing MTA’s with 2 partners to begin evaluation of a total of 23 new, non-commercial products. Nine of 13 new formulations from one partner are performing
well, and 5 of 10 new formulations from another partner are performing well. Both of these MTA partners have formulations that are more durable than the commercially available foul release coatings.

We also signed 3 new MTA’s with new partners. Unfortunately, none of these new formulations from them performed well.

The test trashrack has been in the reservoir for 3 ½ years and was also inspected. It was previously coated with three silicone based FRC and one silicone-epoxy hybrid coating. All the coatings are performing well, although there was some coating damage to the bars where the trashrake glides on the surface. The weight of the trashrack caused cracking and chipping of the coatings. The hard silicone epoxy hybrid had significantly more corrosion on the leading edge of the Seaspeed V5 than the soft FRC.

Results of tests conducted at the test site at Parker Dam are very informative and are key to determining actual field performance of these coating systems. Evaluating coatings at this site should continue. Possible performance improvement of any experimental or new commercial product is only theoretical until proven by field testing for the efficacy of mussel control. Reclamation should continue to support the development of new materials with MTA partners, and field test the new formulations to help improve technologies. The partners have demonstrated durable formulations that perform well in field testing.
Contents

Executive Summary........................................................................................................................................................................ vi
Background..................................................................................................................................................................................9
  Summary of Prior Testing Related to This Report ......................................................................................................................9
  Present Testing.............................................................................................................................................................................10
Exposure Conditions.......................................................................................................................................................................12
Results and Discussion......................................................................................................................................................................12
  Commercially Available Systems.................................................................................................................................................12
  Experimental Systems..................................................................................................................................................................21
  Inspection of Scaled-up Trashrack ...........................................................................................................................................28
Conclusions..................................................................................................................................................................................31
Next Steps................................................................................................................................................................................31
References..................................................................................................................................................................................33

Tables

Table 1. All reports on mussel related activities by Materials and Corrosion Laboratory Researchers 2008-2018. .................................................................................................................................10
Table 2. Commercially available coatings and metal alloys in testing as of this publication date. ...............................................................................................................................................14
Table 3. Coating systems evaluated, but removed from testing .............................................15
Table 4. Experimental formulations from Material Transfer Partner 2012-MTA-8-1003 ...............................................................................................................................................22
Table 5. Experimental formulations from 14-MTA-8-1010..................................................24
Table 6. Additional MTA partnerships experimental formulations...............................................26

Figures

Figure 1. Aerial photo of Parker Dam, CA. The red line indicates the location where the plates were placed, and the yellow line indicates where the grates were placed.12
Figure 2. International Paint Intersleek 970 at five years’ exposure in dynamic conditions, photo taken May 2013.................................................................16
Figure 3. International Paint Intersleek 970 after 10 years’ exposure in dynamic conditions, fouling is easily removed, photo taken April 2018..............................17
Figure 4. Z-Alloy in dynamic exposure after two years’ exposure, photo taken July 2017.18
Figure 5. Sherwin Williams Polysiloxane XLE-80 in dynamic exposure, photo taken December 2015........................ .................................................................19
Figure 6. PPG PSX 700 in dynamic conditions, photo taken December 2015..................20
Figure 7. Sharkskin in dynamic exposure after nine months’ exposure, photo taken April 2018. ............................................................20
Figure 8. 2012-MTA-9-1003 formulation C4-20% after three years’ dynamic water exposure, photo taken July 2017.........................23
Figure 9. 14-MTA-8-1010 formulations 1, 3, 4, 5, & 6 (left to right) after 3 ½ years in dynamic exposure, photo taken April 2018.................................................................25
Figure 10. 14-MTA-8-1010, formulations 7, 8, 9, 10 (left to right), after 3 ½ years in dynamic exposure, photo taken April 2018.................................................................25
Figure 11. 14-MTA-8-1008 experimental formulation after one year of dynamic exposure, photo taken December 2016. ..............................................................................27
Figure 12. 15-MTA-8-2012 #1 after one year of dynamic exposure, photo taken December 2016. .................................................................................................................27
Figure 13. 15-MTA-8-1013 one year of dynamic exposure, photo taken December 2016.28
Figure 14. Scale-up trashrack International Paint Intersleek 970 after 3.5 years exposure, photo taken underwater in July of 2017.................................................................29
Figure 15. Scale-up trashrack PPG Sigmaglide 890 after 3.5 years exposure, photo taken underwater in July of 2017. .................................................................29
Figure 16. Scale-up trashrack Sherwin Williams Sher-Release after 3.5 years exposure (no longer manufactured), photo taken underwater in July of 2017. ..........................30
Figure 17. Scale-up trashrack Seacoat Seaspeed V5 after 3.5 years exposure, photo taken underwater in July of 2017. ........................................................................30
Background

In 2007, quagga mussels were discovered in Lake Mead and subsequently downstream from Hoover Dam. The mussels can tightly adhere to submerged surfaces and can impair function of some hydraulic structures. One approach to prevent or reduce the effects of mussel buildup (fouling) is to use antifouling or FRC. Antifouling coatings contain a biocide (poison) that is designed to deter fouling. FRC’s rely on physical properties of the coating to impair adhesion of the mussel to the coating surface.

In 2008, Reclamation began to evaluate coatings for mussel control at Parker Dam. This site was selected because samples could be easily set along the face of the dam and across the trashrack structure for two different exposure conditions—flowing water and quasi-static water. Service environments at Reclamation facilities present some unique challenges that must be considered when evaluating coatings for fouling control: highly variable water quality and abundant waterborne materials that affect durability, including sediment, woody debris, vegetation, ice, and other debris.

Most of the commercial products tested are designed for fouling control in the marine shipping industry. Ships are recoated every five to six years. Unfortunately, Reclamation’s structures are less accessible, requiring coatings to have a longer service life. Therefore, durability is a primary factor in evaluating materials and coatings. Prior to the emergence of quagga mussels, Reclamation did not have a compelling need for materials and coatings to address fouling problems.

Initial results showed that continuously flowing water along the trashrack structure led to faster fouling rates than areas under quasi-static conditions like those found near the dam face. Reclamation concluded that antifouling coatings were not effective in flowing water but were effective in quasi-static water. This also showed that results from previous research done by other agencies had misleading results because they only evaluated coatings in static conditions.

Summary of Prior Testing Related to This Report

Report ST-2015-7095-01 Coatings for Invasive Mussel Control – Final Report evaluated over 100 materials and coatings under field conditions to determine the types of materials/coatings that prevent mussels from adhering to surfaces. Results from this report showed:

1. Mussel fouling is faster under flowing water conditions.
2. Foul release coatings appeared to be the best option for controlling mussel fouling.
3. Copper and copper alloys can work for antifouling, but efficacy depends upon water chemistry, flow rates, and the corrosion rate of the alloy. Performance of copper alloys may vary between facilities, so it is important to fully evaluate site specific conditions prior to deciding whether to use a copper alloy.
4. Antifouling coatings worked in quasi-static water, but not in constantly flowing water.
Durable, hard hybrid coatings (Jotun Sealion Resilient and formulations from 2012-MTA-8-1003) showed promise as we were closing out this project, justifying the project’s continuation.

Silicone FRC were the best option for mitigation. However, concerns regarding durability prompted a new research project that involved applying silicone FRC on a trashrack panel to determine if the soft coatings would hold up to real-world conditions. Report ST-2015-5270-1 Foul Release Coatings Scale up Testing – Parker Dam Trashrack evaluated three commercially available silicone FRC and one hard epoxy silicone hybrid. After 18 months of exposure the results showed:

1. The three silicone foul release systems had less damage than the hard silicone epoxy hybrid.
2. The three silicone foul release systems had minimal algae on the surface with no attached mussels.
3. The hard silicone epoxy hybrid had heavier fouling than the silicone foul release systems.

All reports describing coating evaluations performed by the Materials and Corrosion Laboratory (MCL) to reduce fouling from mussels conducted over the last ten years (2008-2018) are listed in Table 1.

Table 1. All reports on mussel related studies conducted by the Materials and Corrosion Laboratory Researchers 2008-2018.

<table>
<thead>
<tr>
<th>Titles</th>
<th>Year(s)</th>
<th>Report Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mussel adhesion mechanism</td>
<td>2011</td>
<td>MERL-2011-21</td>
</tr>
<tr>
<td>2 Investigation of molybdenum and tungsten disulfide for mussel control</td>
<td>2011</td>
<td>MERL-2011-37</td>
</tr>
<tr>
<td>3 Overcoating coal tar enamel using FRC</td>
<td>2011</td>
<td>MERL-2011-41</td>
</tr>
<tr>
<td>4 Natural biocides for zebra and quagga mussel control</td>
<td>2011</td>
<td>MERL-2011-46</td>
</tr>
<tr>
<td>5 Advanced review of mussel adhesion</td>
<td>2013</td>
<td>MERL-2013-43</td>
</tr>
<tr>
<td>6 Durable FRC</td>
<td>2012-2013</td>
<td>MERL-2014-57</td>
</tr>
<tr>
<td>7 Coatings for invasive mussel control</td>
<td>2008-2015</td>
<td>ST- 2015-7095-01</td>
</tr>
<tr>
<td>8 FRC scale up testing – Parker Dam trashrack</td>
<td>2013-2015</td>
<td>ST-2015-5270-1</td>
</tr>
<tr>
<td>9 Durable silicone FRC CRADA</td>
<td>2014-2016</td>
<td>ST-2016-0809-01/8540-2016-02</td>
</tr>
<tr>
<td>10 Continuation of field evaluations on advanced coatings for mussel control</td>
<td>2015-2018</td>
<td>ST-2018-7089-01</td>
</tr>
</tbody>
</table>

Present Testing

Work conducted over the past three years is a continuation of previous research which was to:
1. Continue evaluating commercially available foul release materials that were shown to work in previous research.
2. Continue evaluating experimental products that may represent advancements in technology obtained for testing using a Material Transfer Agreements (MTA).
3. Continue evaluating the coated trashrack panel.
Exposure Conditions

Parker Dam, at Lake Havasu Reservoir on the border between Arizona and California (Figure 1), was selected as the field test site to evaluate materials and coatings in quasi-static (low-flowing) and dynamic (flowing) exposure conditions. Mussels at this location on the lower Colorado River reproduce almost year-round and have more reproductive cycles per year than northern climate infestations.

For each coating system tested, three one-square foot steel plates were used in quasi-static exposure. They were secured by a nylon rope and lowered approximately 50 feet (ft.) into the water near the face of the dam. For the dynamic conditions, one 18-inch (in.) by 24-in. coated floor grate with 1-in. spacing was lowered to a depth of approximately 40 ft. below the water’s surface. The samples were hung downstream from the forebay trashrack structure. For velocity measurements and water temperature changes refer to report ST-2015-7095-01.

Results and Discussion

Commercially Available Systems

Table 2 lists the coating systems that are still being tested. Most of the FRC systems are no longer foul resistant and have accumulated fouling on the surface, however, the fouling is easily...
removed with minimal force (no measurable force using a force gauge). All samples, including those with complex geometries, have minimal corrosion after ten years of exposure, indicating they are durable. Figures 2 and 3 show an example of fouling buildup on the silicone FRC subject to dynamic exposure after 5 and 10 years, respectively.

Z-Alloy, a copper alloy, was added to the study in May 2015 and is still being tested. Z-Alloy can be made into intakes and fish screens. No mussels have attached to the test specimens in either quasi-static or dynamic conditions after three years of exposure. Figure 4 shows a Z-Alloy fish screen after two years of exposure.

During the course of this study, some coating systems were removed from testing. These coatings are listed in Table 3. Fuji Film Smart Surfaces was one of the first systems selected for testing at the beginning of the study in May 2008 and was performing well. However, Fuji went out of business in December 2015, thus all Fuji systems (also co-branded as Sherwin Williams Sher-Release) were removed from testing in May 2016.

Sherwin Williams Polysiloxane XLE-80 and PPG PSX 700 systems are designed for atmospheric service and were evaluated since they have graffiti resistance properties. Both systems were removed from testing because they didn’t perform well against mussel fouling (Figures 5 and 6). Sharkskin, a micro/nano texturing polymeric film, (said to mimic shark skin) was evaluated. It was removed from testing in April 2018 due to poor performance (Figure 7).
Table 2. Commercially available coatings and metal alloys in testing as of this publication date.

<table>
<thead>
<tr>
<th>Coating System/ Metal Alloy</th>
<th>Dates of Exposure</th>
<th>Comments from April 2018 inspection</th>
</tr>
</thead>
</table>
| International Paint Intersleek 970 | May 2008 to present | Dynamic: ½” thick biofouling primarily algae, easily cleaned  
Quasi-static: No mussels |
| CMP Bioclean SPG-H | October 2009 to present | Dynamic: ½” thick biofouling primarily algae, easily cleaned  
Quasi-static: some mussels attached to algae, easily cleaned |
| PPG Sigmaglide 890 | October 2009 to present | Dynamic: minimal biofouling primarily algae, easily cleaned  
Quasi-static: No mussels |
| Hempel Hempasil X3 | December 2012 to present | Dynamic: ½” thick biofouling primarily algae, easily cleaned  
Quasi-static: No mussels |
| International Paint Intersleek 425 | December 2012 to present | Dynamic: Lost coated grate  
Quasi-static: No mussels |
| Nusil 9707 | May 2012 to present | Dynamic: ½” thick biofouling primarily algae, easily cleaned  
Quasi-static: Few mussels, easily cleaned |
| Jotun Sealion Repulse | May 2013 to present | Dynamic: minimal biofouling primarily algae, easily cleaned  
Quasi-static: No mussels |
| Jotun Sealion Resilient | May 2013 to present | Dynamic: ¾” thick biofouling primarily algae, easily cleaned  
Quasi-static: Many mussels, not as easily cleaned as the silicones |
| Silicone Solutions F-23 | December 2014 to present | Dynamic: ½” thick biofouling primarily algae, easily cleaned  
Quasi-static: few mussels, easily cleaned |
| Silicone Solutions SS5000A | December 2014 to present | Dynamic: ¾” thick biofouling primarily algae, easily cleaned  
Quasi-static: few mussels, easily cleaned |
| Z-Alloy | May 2015 to present | Dynamic: no mussels attached, but mussels are caught up in turbulence due to attachment to floor grate.  
Quasi-static: no mussels present |
Table 3. Coating systems evaluated, but removed from testing

<table>
<thead>
<tr>
<th>Coating System</th>
<th>Dates of Exposure</th>
<th>Comments from time of removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuji Film Smart Surfaces (also referred as Sherwin</td>
<td>May 2008 to May 2016</td>
<td>No fouling, removed due to company no longer manufacturing product</td>
</tr>
<tr>
<td>Williams Sher-Release)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Sherwin Williams Polysiloxane XLE-80                | May 2015 to December 2015 | Dynamic: Heavy mussel fouling, difficult to remove fouling  
Quasi-static: Heavy mussel fouling, difficult to remove fouling |
| PPG PSX 700                                          | May 2015 to December 2015 | Dynamic: Heavy mussel fouling, difficult to remove fouling  
Quasi-static: Heavy mussel fouling, difficult to remove fouling |
| Sharkskin                                            | July 2017 to April 2018    | Dynamic: Heavy mussel fouling, difficult to remove fouling  
Quasi-static: Heavy mussel fouling, difficult to remove fouling |
Figure 2. International Paint Intersleek 970 at five years’ exposure in dynamic conditions, photo taken May 2013.
Figure 3. International Paint Intersleek 970 after 10 years’ exposure in dynamic conditions, fouling is easily removed, photo taken April 2018.
Figure 4. Z-Alloy in dynamic exposure after two years’ exposure, photo taken July 2017.
Figure 5. Sherwin Williams Polysiloxane XLE-80 in dynamic exposure, photo taken December 2015.
Figure 6. PPG PSX 700 in dynamic conditions, photo taken December 2015.

Figure 7. Sharkskin in dynamic exposure after nine months’ exposure, photo taken April 2018.
Experimental Systems

MTA’s were set up with each company to evaluate each partner’s experimental formulations. MTA’s are designed to protect intellectual property while allowing us to perform evaluations about whether the coating is successful at preventing mussel attachment. After the MTA’s were signed, partners sent samples to Reclamation researchers to be installed at the Parker Dam test site. Periodic inspections were conducted to evaluate the effectiveness of each experimental coating and travel reports were written to document observations and sent to the MTA partner.

MTA partner 2012-MTA-8-1003 utilized this arrangement to further advance their technology by verifying formulation reproducibility and advancing new formulations of durable foul release technology. The partner has submitted materials for three different rounds of testing. Some were also submitted to determine reproducibility of results and are shown in Table 4. Many of the experimental formulations perform as well as the commercial FRC.

Figure 8 shows C4-20% after three years of flowing water exposure. The coating surface remains mussel free while the surrounding area has significant mussel buildup. The panels were secured by zip ties and the mussels fouled the zip ties.
<table>
<thead>
<tr>
<th>Experimental Formulation</th>
<th>Dates evaluated</th>
<th>Comments for dynamic exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-10%</td>
<td>December 2012 to May 2014</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>A-20%</td>
<td>December 2012 to May 2014</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>C-10%</td>
<td>December 2012 to present</td>
<td>100% covered, easily cleaned after 5 ½ years, prevented fouling through 5 years</td>
</tr>
<tr>
<td>C-20%</td>
<td>December 2012 to present</td>
<td>100% covered, easily cleaned after 5 ½ years, prevented mussels through 5 years</td>
</tr>
<tr>
<td>PDMSA-4/PDMS-16</td>
<td>August 2014 to May 2015</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>PDMSA-8/PDMS-12</td>
<td>August 2014 to May 2015</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>A4-20%</td>
<td>August 2014 to December 2015</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>C4-20%</td>
<td>August 2014 to present</td>
<td>10% covered, as easy to clean as commercial FRC after 3 3/4 years</td>
</tr>
<tr>
<td>SO-PMM-0021</td>
<td>August 2014 to present</td>
<td>100% covered, as easy to clean as commercial FRC after 3 3/4 years</td>
</tr>
<tr>
<td>SO-PMM-0025</td>
<td>August 2014 to December 2015</td>
<td>100% covered, not as easy to clean as commercial FRC after 18 months</td>
</tr>
<tr>
<td>SB-304-9</td>
<td>July 2017 – present</td>
<td>100% covered, not as easy to clean as commercial FRC after 1 year</td>
</tr>
<tr>
<td>F12</td>
<td>July 2017 – present</td>
<td>10% covered, as easily cleaned as commercial FRC after 1 year</td>
</tr>
<tr>
<td>F11</td>
<td>July 2017 – present</td>
<td>50% covered, not as easy to clean as commercial FRC after 1 year</td>
</tr>
<tr>
<td>F6</td>
<td>July 2017 – present</td>
<td>70% covered, as easily cleaned as commercial FRC after 1 year</td>
</tr>
<tr>
<td>SO-0021</td>
<td>July 2017 – present</td>
<td>70% covered, as easily cleaned as commercial FRC after 1 year</td>
</tr>
<tr>
<td>AMP-GC-R6-5%-2432</td>
<td>July 2017 – present</td>
<td>70% covered, as easily cleaned as commercial FRC after 1 year</td>
</tr>
<tr>
<td>F30-IGC-PACM</td>
<td>July 2017 – present</td>
<td>100% covered, as easily cleaned as commercial FRC after 1 year</td>
</tr>
</tbody>
</table>
MTA partner 2014-MTA-8-1010 provided ten experimental formulations. Five formulations are performing as well as the commercially available FRC, shown in Table 5. Four other formulations have more fouling buildup than commercially available FRC and are moderately easy to remove. Fouling was difficult to remove from one formulation. Figures 9 and 10 show the latest photos of the specimens coated with these formulations.
Table 5. Experimental formulations from partner 14-MTA-8-1010

<table>
<thead>
<tr>
<th>Experimental Formulation</th>
<th>Dates tested</th>
<th>Comments for dynamic exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-MTA-8-1010 #1</td>
<td>December 2014 to present</td>
<td>50% covered, as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #2</td>
<td>December 2014 to December 2015</td>
<td>100% covered, moderately easy to clean, not as easily cleaned as commercial FRC after 1 year</td>
</tr>
<tr>
<td>14-MTA-8-1010 #3</td>
<td>December 2014 to present</td>
<td>100% covered, as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #4</td>
<td>December 2014 to present</td>
<td>100% covered, as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #5</td>
<td>December 2014 to present</td>
<td>100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #6</td>
<td>December 2014 to present</td>
<td>100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #7</td>
<td>December 2014 to present</td>
<td>100% covered, as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #8</td>
<td>December 2014 to present</td>
<td>100% covered, as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #9</td>
<td>December 2014 to present</td>
<td>100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
<tr>
<td>14-MTA-8-1010 #10</td>
<td>December 2014 to present</td>
<td>100% covered, significant buildup, moderately easy to clean, not as easy to clean as commercial FRC after 3 1/2 years</td>
</tr>
</tbody>
</table>
Figure 9. Partner 14-MTA-8-1010 formulations 1, 3, 4, 5, & 6 (left to right) after 3 ½ years in dynamic exposure, photo taken April 2018.

Figure 10. 14-MTA-8-1010, formulations 7, 8, 9, 10 (left to right), after 3 ½ years in dynamic exposure, photo taken April 2018.
Additional MTAs provided for more experimental formulations, but mussels attached and were
difficult to remove as shown in Table 6. Unfortunately, this means that mussels will build up
and the surfaces will never be completely free of fouling.

Figure 11 shows a test specimen coated with the 14-MTA-8-1008 (#1) formulation after one year
in dynamic exposure. There is extensive mussel buildup on this coating. Figure 12 is a photo of
15-MTA-8-1012 formulation #1 after one year of dynamic exposure. A few mussels attached to
the surface and were very difficult to remove, leaving the byssal threads on the coating surface.
Figure 13 is a photo of the 15-MTA-8-1013 #1 experimental formulation after six months of
exposure. Mussels attached to the surface and required significant force to remove them
resulting in breaking their shells. All three of these MTA partner experimental systems were
removed from testing in December 2016.

<table>
<thead>
<tr>
<th>Experimental Formulations</th>
<th>Dates Evaluated</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-MTA-8-1008 #1</td>
<td>12-2015 to 12-2016</td>
<td>100% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1012 #1</td>
<td>12-2015 to 12-2016</td>
<td>50% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1012 #2</td>
<td>12-2015 to 12-2016</td>
<td>50% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1012 #3</td>
<td>12-2015 to 12-2016</td>
<td>50% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1012 #4</td>
<td>12-2015 to 12-2016</td>
<td>50% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1012 #5</td>
<td>12-2015 to 12-2016</td>
<td>50% covered, not easy to clean, after 1 year</td>
</tr>
<tr>
<td>15-MTA-8-1013 #1</td>
<td>6-2016 to 12-2016</td>
<td>100% covered, not easy to clean, after 6 months</td>
</tr>
</tbody>
</table>
Figure 11. 14-MTA-8-1008 #1 experimental formulation after one year of dynamic exposure, photo taken December 2016.

Figure 12. 15-MTA-8-2012 #1 after one year of dynamic exposure, photo taken December 2016.
Inspection of Trashrack Specimen

The trashrack inspection showed that after three and a half years the three FRC Intersleek 970, Sigmaglide 890, and Sher-Release had minimal fouling (primarily algae) on the surface with damage to the bars where the trashrake glides on the surface. The PPG Sigmaglide 890 and Seacoat Seaspeed V5 had more fouling on the surface due to being in deeper water. The majority of the corrosion was on the leading edge of the bars that contained the hard silicone/epoxy hybrid Seaspeed V5. The weight of the trashrake caused cracking and chipping of the coating. Figures 14-17 show the condition of the trashrack coatings after 3.5 years while in service.
Figure 14. International Paint Intersleek 970 after 3.5 years exposure, photo taken underwater in July of 2017.

Figure 15. Sigmaglide 890 after 3.5 years exposure, photo taken underwater in July of 2017.
Figure 16. Sherwin Williams Sher-Release after 3.5 years exposure (no longer manufactured), photo taken underwater in July of 2017.

Figure 17. Seacoat Seaspeed V5 after 3.5 years exposure, photo taken underwater in July of 2017.
Conclusions

Commercial FRC began fouling with algae followed by mussels that attached to the algae. The fouling builds up and the coatings are no longer self-cleaning under the test conditions at Parker Dam. However, the fouling could be easily removed from the panels’ surface.

MTA partner 2012-MTA-8-1003 developed thirteen additional FRC formulations for evaluation. Nine of the thirteen experimental formulations remain in testing and are performing as well as the commercially available FRC. This partner has patent licenses available for manufacturers to take the products to commercialization.

Another partner, 2014-MTA-8-1010, provided ten experimental products of which five are performing as well as commercially available FRC.

Three new MTA’s were signed with three manufacturers that developed experimental products. Unfortunately, none of these experimental products prevented fouling and the fouling was more difficult to remove than the other FRC tested.

The trashrack specimen inspection showed that after three and a half years the three FRC had minimal fouling, (primarily algae) on the surface with damage to only the bars where the trashrake slides on the surface. The PPG Sigmaglide 890 and Seacoat Seaspeed V5 had more fouling due to being in deeper water. The majority of the corrosion was on the leading edge of the bars that contained the hard silicone/ epoxy hybrid. The weight of the trashrake caused cracking and chipping off the coating leading to the corrosion. It was originally thought that the hard silicone hybrid would have been more corrosion resistant than the soft silicone FRC.

Next Steps

Field testing needs to continue in order to advance new technologies. The performance of new products is only theoretical until actual performance has been confirmed by field evaluation for mussel control.

This past year, Pacific Northwest National Laboratory (PNNL) contacted the principle investigator about coatings technology they were developing and wanted to collaborate with Reclamation to have the samples evaluated at the Parker Dam test site. As PNNL develops viable candidates, Reclamation will incorporate them into field testing.

The Army Corps of Engineers also want to study the mussels’ adhesion mechanism in detail and wants to perform large scale testing of FRC previously evaluated by Reclamation to determine if they are durable enough for their service conditions. Reclamation has already provided them all the data collected to date and has provided them information about lessons learned. Reclamation will provide support for their efforts and plans to be onsite when they apply the coatings on their infrastructure to make sure they are applied correctly.
In 2018, Reclamation held a prize competition for the public to suggest solutions for mussel eradication. Three coatings-related solutions were submitted that have the potential to prevent mussel attachment and not eradication. These solutions should be investigated at Parker Dam test site as prevention methods.

As new materials are developed with MTA partners or new partners, Reclamation will continue to support the development of their anti-fouling coatings through comprehensive testing to advance the technologies that work. The group of partners has clearly demonstrated many formulations that work in field testing that are more durable than the commercially available FRC.
References